Acoustic Seaglider™ for Beaked Whale Detection

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LONG-TERM GOALS

This effort exists within a group dedicated to the use of autonomous underwater vehicles, and buoyancy-driven gliders in particular, to support Navy missions. The group generally uses the Seaglider™, developed at the Applied Physics Laboratory of the University of Washington (APL-UW), and develops or adapts instruments and glider behavior to support the mission requirements. This group is usually called the Applied Seaglider™ Group, whose acronym, ASG, is also used to describe the Applied Seaglider™itself.

This report describes our efforts as part of the ONR Passive Autonomous Acoustic Monitoring (PAAM) program. The long-term goals of the PAAM program are as follows.

- Perform persistent and autonomous passive acoustic monitoring of a 500-1000 square-nautical-mile Navy exercise area for presence of marine mammals.
- Monitor for three weeks prior to, three weeks during, and three weeks after a typical exercise.
- Detect, classify and localize vocalizing marine mammals.
- Provide actionable information in a timely manner to the officer in tactical command to support marine mammal mitigation efforts.

OBJECTIVES

We have enhanced the passive acoustic detection, recording, and on-board processing capabilities of Applied Seaglider™ (ASG), with particular attention to the automated detection and classification of beaked whale vocalizations. In particular, we have designed and built a new passive acoustic

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14. ABSTRACT
This effort exists within a group dedicated to the use of autonomous underwater vehicles, and buoyancy-driven gliders in particular, to support Navy missions. The group generally uses the Seaglider?, developed at the Applied Physics Laboratory of the University of Washington (APL-UW), and develops or adapts instruments and glider behavior to support the mission requirements. This group is usually called the Applied Seaglider? Group, whose acronym, ASG, is also used to describe the Applied Seaglider?itself.

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detection and recording system for ASG, and begun to test this system in the field. Objectives remain to enhance performance with multiple hydrophones or small hull-mounted hydrophone arrays, improve the automated detection and classification (software) components, and test the system on instrumented Navy ranges, coordinated with other PAAM performers and (perhaps) subsequent Navy fleet exercises.

APPROACH

We have chosen to focus on automated detection, classification, and recording of beaked whale vocalizations. Beaked whales vocalize at depths greater then 200m and use frequencies above 25kHz, characteristics that are a good fit with the ASG's depth range and physical dimensions.

Our approach is as follows.

- Design and build a new acoustic detection and recording system with sufficient sampling rates, processing power, and storage capacity to enable ASG as an effective platform for beaked whale detection and recording.
- Collaborate with Drs. David Mellinger and Holger Klinck at Oregon State University (OSU) on beaked whale detection and classification algorithms.
- Conduct a series of bench and in-water tests to characterize system performance.
- Deploy locally in the presence of killer whales (*Orcinus orca*) as a proxy for beaked whales.
- Deploy off Kona (west) coast of island of Hawai'i on beaked whale survey mission.
- Plan for deployment on instrumented Navy range.

Key participants at APL-UW, in addition to the Principal Investigators shown above, are Bill Jump (hardware and system design engineer), Geoff Shilling (software engineer), John Pyle (software engineer), Trina Litchendorf (ASG Lab), and Angie Wood (ASG Lab). Drs. Mellinger and Klinck at OSU are providing detection and classification algorithms, and are collaborating on the implementation of these algorithms.

WORK COMPLETED

Design, fabrication, and testing of the new PAAM acoustic detection and recording system were completed. The present system consists of a single omnidirectional HTI-99-HF hydrophone and our custom designed and built electronics board. The hydrophone is mounted external to the Seaglider aft fairing, at the dorsal centerline, and cabled to the PAAM electronics board via a connector on the Seaglider pressure hull end cap, as shown in Figure 1.

The PAAM electronics board is 21.5cm x 8.3cm x 2.5cm, and fits in the Seaglider electronics bay just underneath the Seaglider main board. The PAAM board itself is shown in Figures 2 and 3. Its main features are given below.

- 4 channels, 16-bit sampling
- 250ksps aggregate sample rate
- Plug-in passive filters (TTE)
- Optional active filters (jumper selectable)
- 64 GB solid-state storage (2 x 32 GB SD cards)
- ARM-9 processor running Linux (13-208 MHz clock)

- Estimated power consumption (@208 MHz)
  - 1 Channel : 756 mW
  - 2 Channels: 879 mW
  - 4 Channels: 1124 mW

Software was written to buffer the digitized data stream, record data to SD cards, implement on-the-fly time-domain click detectors, and control the PAAM system through the Seaglider™ Iridium telemetry. This required completion of a substantial amount of low-level software: CPLD code, SPI bus drivers, SD card drivers, and Linux kernel modifications, in addition to modifications to the existing Seaglider™ and basestation code. A major focus of the software effort was performance – all processes had to be able to keep up with the fast sample rates (≥192k samples per second) demanded by the frequency content of beaked whale clicks.

The PAAM board is controlled via the Seaglider™ worldwide Iridium telemetry link. Various aspects of the board's configuration are under parameter control by the pilot; the board itself may be turned on and off by the Seaglider™ in response to the pilot's settings. For example, a pilot may choose to only activate the PAAM board below a specified depth, or only in accordance with a specified time schedule, or only when the Seaglider™ itself is quiet (no motors are active). Recorder and detector log and statistics files are transmitted from the Seaglider™ to the basestation following each dive.

Full suites of performance characterization and calibration tests were done. The sequence began with functional board-level bench tests and extensive runs on a Seaglider™ test bed at APL-UW. Simple calibration tests of the PAAM system were conducted at the APL-UW dock facilities, using a calibrated source. These tests validated the analog signal path and calculated gains for the PAAM system. Additional calibration tests were used to determine an approximate detection range for beaked whale clicks (at frequency and source levels described in Zimmer *et al.* [**2008**] and consistent with Johnson *et al.* [**2004**] and Zimmer *et al.* [**2005**]).

On 4SEP2009, Seaglider™ SG022 was deployed from Western Washington University's R/V ZOEA in the eastern part of Juan de Fuca and Haro Straits off San Juan and Lopez Islands. Conditions were calm, visibility was excellent, and portions of all three pods of southern resident killer whales (*Orcinus orca*) were present at various times.

SG022 completed five dives in water depths between 60m to 120m. SG022 was positioned at the start of each dive at ranges to the killer whale pods of between 0.8km and 3.5km. The PAAM board was configured to run the automated click detector, and also to record the complete acoustic time series during each dive. A total of 3.7 GB of acoustic data was recorded, representing 168 minutes of recording.

RESULTS

The recordings made on 4SEP2009 by the PAAM system on Seaglider™ SG022 are rich in content. In addition to the recognizable killer whale calls and echolocation clicks, one can clearly identify sounds associated with the Seaglider™ itself: wave slap against the hydrophone when SG022 is at the surface, the pitch and roll motors as they activate to control the Seaglider™'s attitude, and the main pump of the Variable Buoyancy Device (VBD) as SG022 changes its buoyancy. One can also identify sounds associated with the fleet of whale watching boats that surround and follow the killer whale pods, and the fleet of purse seiners engaged in commercial salmon fishing nearby.

Spectrograms of the recorded data clearly show the killer whale calls and echolocation clicks. A representative spectrogram is shown in Figure 4.

The automated click detector developed by Drs. Mellinger and Klinck at OSU was run during all dives, with results uploaded to the basestation. The statistics output summary of the on-the-fly detections during the dive phase of SG022's dive 3 on 4SEP2009 is shown below. Each line in the table below represents approximately one minute of examined data; climb phase statistics from dive 3 are not shown due to space considerations.

Depth(m)	Detections	Detections in ICI	Threshold	Min. Threshold Exceeded	Max. Threshold Exceeded	Mean Threshold Exceeded
0.43	467	266	72.57	0.42	318.74	49.21
1.09	930	744	82.16	0.06	432.41	97.78
1.95	818	599	86.35	0.38	423.91	95.93
16.05	616	409	85.58	0.03	426.43	99.97
28.34	413	134	83.18	0.20	350.28	83.31
43.34	448	142	90.06	0.06	267.34	71.69
58.52	240	54	87.41	0.10	204.11	43.19
69.88	90	9	81.69	0.03	165.42	30.00
78.39	6	0	72.32	18.91	63.20	39.43
86.32	9	1	67.93	3.63	217.70	54.63
86.30	3	0	69.82	42.14	338.80	144.97
86.44	3	0	40.62	42.06	81.78	61.97
86.31	1	0	31.29	23.83	23.83	23.83

Note that many click detections were made at the top of the dive and on the initial part of the descent. SG022 was intentionally rested on the bottom at about 86m, but by then the killer whale pod had opened the range, some one-minute recording periods were dominated by self-noise from the main VBD pump, and there was intervening topography obstructing the acoustic paths from the animals. As confidence is built with the detectors and (yet-to-be-installed) classifiers, these statistical summaries should provide sufficient information on which to base decisions about on-board recording, off-board reporting and data transmission.

The first sea trial of the PAAM detector and recorder in the presence of marine mammals was completely successful. Killer whales were used as a proxy for beaked whales; the automated click detector worked as expected. The computational system was able to keep up with a nominal digitization rate of 192k samples per second, sufficient to resolve beaked whale echolocation clicks. Further data analysis is currently underway, but we have sufficient confidence in the system to plan a three-week deployment off the Kona (west) coast of the island of Hawai'i in late-October and early-November. Deployment locations and timing have been guided by Baird *et al.* [**2006**] and McSweeney *et al.* [**2007**].

IMPACT/APPLICATIONS

The Seaglider™/PAAM detection and recording system has achieved an initial operational capability. Additional testing and system characterization is required, particularly on an instrumented Navy range such as AUTEC. The use of a range's fixed hydrophone array to provide ground-truth tracking of marine mammals is critical to the accurate characterization of the performance of the Seaglider™/PAAM system.

The Seaglider™/PAAM system has the frequency range, computational power and flexibility, and persistence to be capable of a wide range of passive acoustic detection and recording missions. It is especially suitable for higher-frequency applications, where hydrophones can be small and large acoustic aperture is not required. The multi-channel electronics and sophisticated computational capability make integrating lower-frequency systems feasible.

RELATED PROJECTS

There are many related projects to use passive acoustics to detect, classify, and monitor marine mammals; some are funded as part of ONR's broader PAAM program, some are supported elsewhere.

Dr. David Mellinger at OSU is directly funded by ONR under the PAAM program to provide beaked whale detection and classification algorithms. His annual report will cover these contributions in more detail.

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FIGURES

Figure 1. Seaglider™ SG022 during pre-launch check-out in the eastern Strait of Juan de Fuca on 4SEP2009, showing installation of HTI-99-HF omnidirectional hydrophone outside the upper surface of the aft fairing, just forward of the vertical stabilizer.

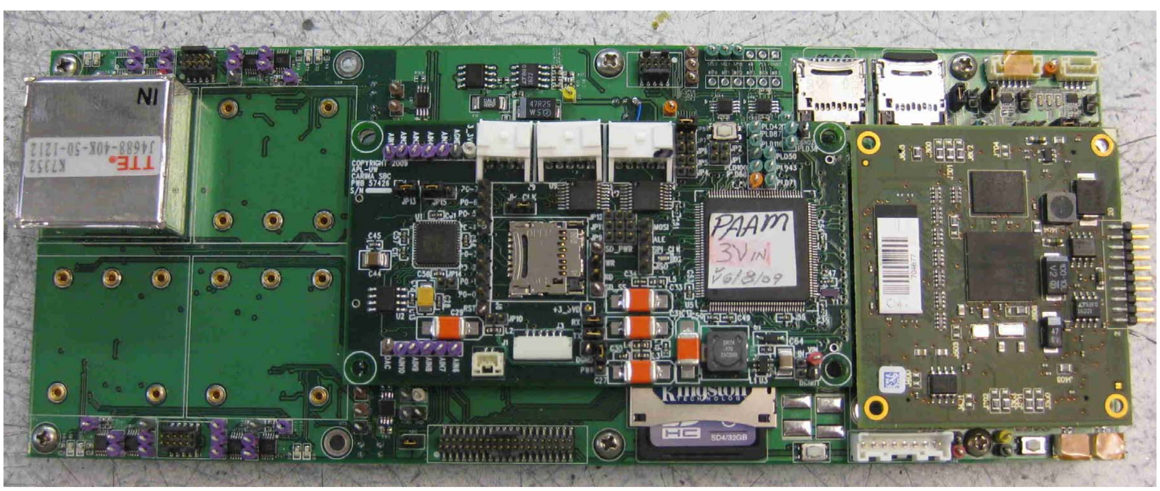

Figure 2. Seaglider™ PAAM electronics board, top view. The board has four analog channels; one analog filter (of four possible) is installed in upper-left corner of board. The daughter board in the middle is the ADuC845 microcontroller card. The daughter board on the right is the LPC3180 ARM9 CPU (with FPU), running Linux. Note SD card slot at lower edge of board.

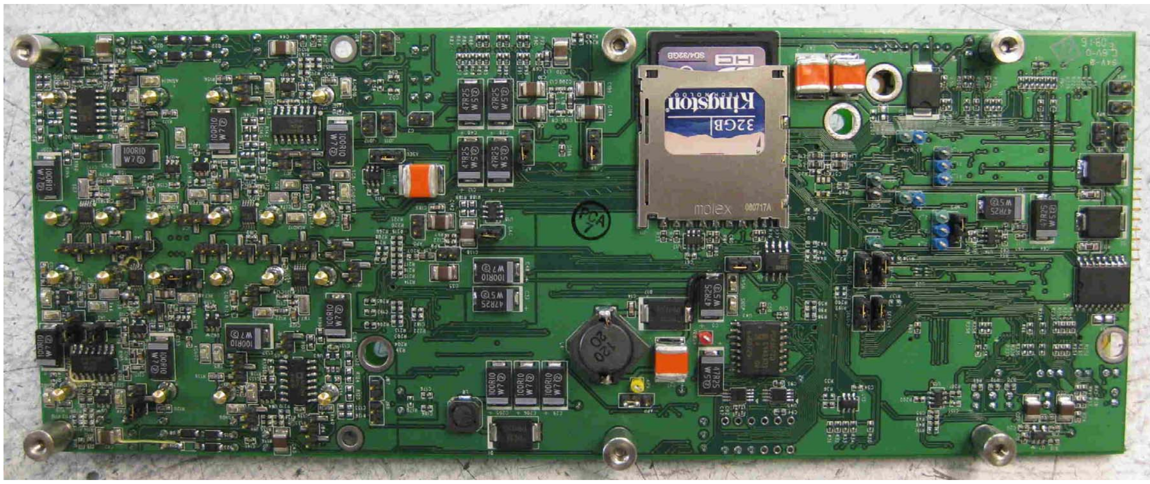

Figure 3. Seaglider™PAAM electronics board, bottom view. Note second SD card slot.

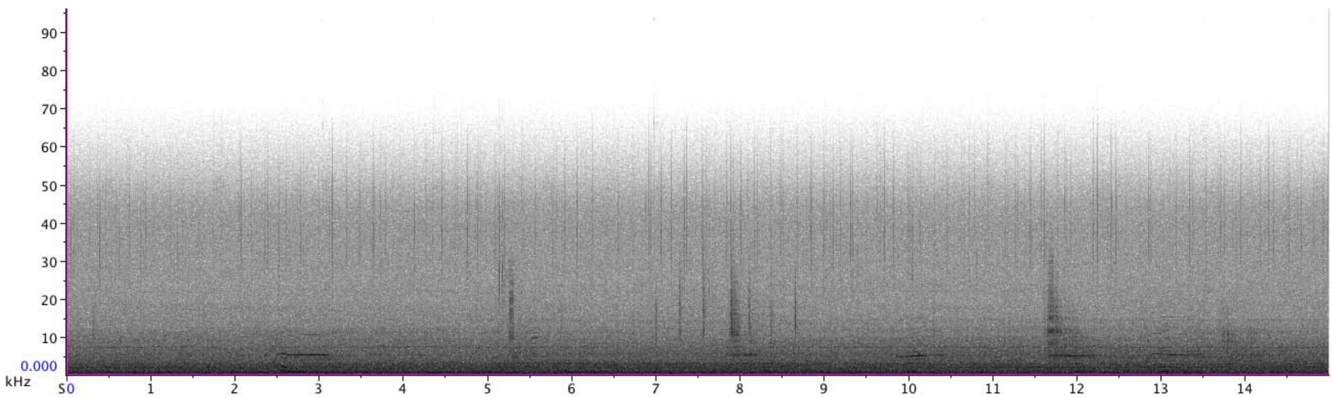

Figure 4. Spectrogram from dive 3 of SG022's deployment within about 2km of killer whales **(Orcinus orca)** ***off San Juan Island, WA, 4SEP2009. The analog hydrophone signal was digitized at approximately 192k samples per second. Note killer whale calls centered around 5kHz starting at t=2.5s, and click trains, low-rate, then high-rate, then low-rate, centered around 20kHz, between t=7s and t=9s.***